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The Effects of Vehicle Model and Driver Behavior on Risk

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ABSTRACT

We study the dependence of risk on vehicle type and especially on vehicle model. Here risk is measured by the number of driver fatalities per year per million vehicles registered. We analyze both the risk to the drivers of each vehicle model and the risk the vehicle model imposes on drivers of other vehicles with which it crashes. The ”combined risk“ associated with each vehicle model is simply the sum of the risk-to-drivers in all kinds of crashes and the risk-to-drivers-of-other-vehicles in two-vehicle crashes. We find that most car models are as safe to their drivers as most sport utility vehicles (SUVs); the increased risk of a rollover in a SUV roughly balances the higher risk for cars that collide with SUVs and pickup trucks. We find that SUVs, and to a greater extent pickup trucks, impose much greater risks than cars on drivers of other vehicles; and these risks increase with increasing pickup size. The higher aggressivity of SUVs and pickups makes their combined risk higher than that of almost all cars. Effects of light truck design on their risk are revealed by the analysis of specific models: new unibody (or “crossover”) SUVs appear, in preliminary analysis, to have much lower risks than the most-popular truck-based SUVs. Much has been made in the past about the high risk of low-mass cars in certain kinds of collisions. We find there are other plausible explanations for this pattern of risk, which suggests that mass may not be fundamental to safety. While not conclusive, this is potentially important because improvement in fuel economy is a major goal for designers of new vehicles. We find that accounting for the most risky drivers, young males and the elderly, does not change our general results. Similarly, we find with California data that the high risk of rural driving and the high level of rural driving by pickups does not increase the risk-to-drivers of

pickups relative to that for cars. However, other more subtle differences in drivers and the driving environment by vehicle type may affect our results.

Keywords: driver fatalities, sport-utility vehicles; light trucks; injury risk

1. Introduction

There are two general methods to analyze the effect of vehicle design on safety. The first is based on laboratory tests of the ability of a vehicle to protect its occupants once a serious crash occurs ("crashworthiness"; e.g. the National Crash Assessment Program, or NCAP, and tests by the Insurance Institute for Highway Safety, or IIHS) and the handling of a vehicle and its ability to avoid a crash ("crash avoidance"; such as Consumer Reports' braking and handling tests). However, these tests are quite expensive, and therefore are usually conducted on a single vehicle from a particular model. In addition, these tests cannot replicate the variety in the kinds of crashes (e.g. crashes at different angles with different kinds of vehicles or roadside objects); nor do they address the likelihood of different kinds of crashes (e.g. for the driver to lose control over the vehicle). The second method is to utilize data from real-world crashes. The practical limitation of this approach is that it is very difficult to separate the effect of the vehicle from the effect of the driver and driving environment in analyzing fatalities or injuries.

In this study we use data on real-world crashes to explore the role of vehicle design in traffic fatalities in the hope of understanding the effect design differences have on safety. The fundamental problem in assessing the risks associated with vehicle designs is that both vehicle design and driver behavior (how, where, and when the vehicle is driven and how it is maintained) affect risk. Various analyses approach this fundamental difficulty in different ways, and none are completely satisfactory. In addition, vehicle design can influence not only its crash avoidance and crashworthiness, but also whether it endangers the occupants of other vehicles with which it may crash ("compatibility").

The risks related to vehicle design depend on many characteristics, including specific safety technologies and features such as frontal height and stiffness, as well as gross dimensions like size and mass. These vehicle characteristics tend to be correlated with each other in historical data, and they also can correlate with driver behavior. For example, higher quality vehicles may tend to be purchased by more careful drivers. And vehicle size has been strongly correlated with vehicle mass, although this relationship may be changing with the introduction of new mass reduction technologies.

The critical issue for this analysis is to evaluate vehicle-design aspects of traffic deaths. Our method for addressing this emphasizes the dependence of traffic risks on individual vehicle models. The motive for this approach is to help make the analysis more transparent by bringing knowledge about individual vehicle models, including characteristics and behavior of their drivers, as well as where they are driven, to bear.

2. Data and Methods

In this analysis we use the word *risk* as a technical term, defining it as driver deaths per year per million registered vehicles (similar to IIHS). We focus on driver deaths because that eliminates variations in the number of passengers among vehicle types and models that could affect our results. Following Joksch et al., 1998, we are concerned with two risks, the ”risk-to-drivers“ of the subject vehicle model (or vehicle type) and the ”risk-to-drivers-of-other-vehicles“ that crash with the subject vehicle (which we often abbreviate as “risk-to-others”). The risk-to-drivers includes driver fatalities from all kinds of collisions, whether with another vehicle, an object other than another vehicle in use, or a pedestrian or pedal-cyclist, as well as non-collisions (rollovers). The risk-to-drivers-of-other-vehicles includes fatalities when the subject vehicle collides with another vehicle. The other vehicle may be of any model year or type (including motorcycles, buses, and heavy-duty trucks).

The ”combined risk“ associated with each vehicle type or model is simply the sum of the risk-to-drivers and the risk-to-drivers-of-other-vehicles. In calculating combined risk there is a problem with double-counting some fatalities. For example, in a collision between two 1997 Honda Civics which kills both drivers, the two fatalities are included in both the risk-to-driver and the-risk-to-drivers-of-other-vehicles, and double-counted in the combined risk. This effect is negligible, less than 2% of the combined risk, for all models, including those with very high registrations (Ford and Chevrolet/GMC 1/2-ton pickups).

We calculate each of these risks using the Fatality Analysis Reporting System (FARS), an annual compilation of all crashes on public roadways which involve at least one fatality within one month of the crash. FARS includes a record on essentially all fatal crashes, with about 340 variables for each. It includes detailed information on each vehicle, driver, and occupant involved in each crash. In most of our analyses we use the number of driver fatalities during the period 1997-2001 for selected vehicle types/models from model years 1997 to 2001. We divide the number of fatalities for a given vehicle type or model by the number of ”registration-years“ of such vehicles as of January 2002. To calculate registration-years we obtained the number of registered vehicles as of January 2000 and January 2002 from R.L. Polk & Company. We then make three adjustments to the registration data to obtain registration-years. First, we approximate the number of registered vehicles in a given year by the number registered in January 2002, after correcting for vehicle attrition over time by comparing the number of each model registered in 2000 with the number registered in 2002. (It would be better to calculate risks using the actual number of registered vehicles for each model year and each calendar year; however, the data required to make these calculations were not readily available.) Then we adjust the number of registration years by 0.7 for the first year of a new model year, since at the end of any calendar year the average new vehicle has been on the road for 8.5 months. For example, the average MY 2001 vehicle is sold in roughly mid-April of 2001 (8.5 months before the end of 2001). Finally, we multiply the adjusted registrations of a particular model year by the number of years that model year has been on the road. To illustrate, a vehicle model with the same number of initial registrations N in each model year would have 13.5 * N registration-years of exposure after 5 years (4.7 + 3.7 + 2.7 + 1.7 + 0.7 = 13.5). Therefore our risks represent the number of fatalities per year per million vehicles in use.

For example, the risk to the drivers of model-year 1997 to 2001 Toyota Camrys is the number of driver fatalities in fatal crashes in the period 1997-2001 in those Camrys (234) divided by the number of registration-years of the Camrys, based on January 2002 registrations and adjusted for attrition (5.51 million), or 42. The risk-to-drivers-of-other-vehicles imposed by Camrys is simply the driver fatalities in all other vehicles which crash with model year 1997 to 2001 Camrys, over the same denominator.

Our analysis by popular model enables us to consider the variability in risk with respect to several variables in a fully transparent manner. For example, we examine risks associated with design characteristics of SUVs, the preference of the elderly or young males for certain models, and the tendency for certain models to be used in rural areas. The 92 "popular" vehicle models have large and steady sales with about 0.4 million registration-years or more over the five-year period. The 49 “most-popular” vehicle models are defined as those with more than one million registration-years over the five-year period (i.e. that have on average 74,000 vehicles registered per year per model year). Table 1 shows that most registered vehicles are included even in our "most popular" category.

Table 1. Percent of all registered vehicles analyzed

Vehicle type	Most popular models (more than 1.0 million registration-years)	Popular models (more than 0.3 million registration-years)
Cars	55%	72%
Minivans	68%	87%
SUVs	78%	94%
Pickups	74%	96%

We group the vehicle models into several vehicle types, or classes, of cars, minivans, and sport utility vehicles (SUVs), as well as into compact and 1/2-ton, 3/4-ton, and 1-ton pickup trucks. In the US SUVs appear in both 2-wheel drive and 4-wheel drive versions. The models included in each group, and their adjusted registration-years, are shown in Tables 2 through 4. However, while presentation of results by vehicle type is appealingly simple, classification by vehicle type may be misleading because the results can be strongly influenced by subjective decisions to include or omit certain vehicle models in different categories. For example, we intentionally divide the subcompact models into two groups, based on the observed risk to their drivers, in order demonstrate the large range in risk-to-drivers of individual subcompact models.

Table 2. Popular and most-popular 1997 to 2001 car models analyzed, with millions of registration-years, risk-to-drivers, risk-to-drivers-of-other-vehicles, and combined risk, through 2001 per model. The most-popular models are shown in bold italics.

Vehicle type	Vehicle make and model	Millions of registration-years	Average risk and 95% confidence intervals: Risk-to-drivers	Risk-to-others	Combined risk
Subcompact cars (low-risk)	***Honda Civic/CRX/del Sol***	***4.54***	***81 ± 8***	***24 ± 4***	***105 ± 9***
	Saturn SC/SL/SW	***3.18***	***93 ± 11***	***24 ± 5***	***117 ± 12***
	Toyota Corolla	***3.07***	***84 ± 10***	***31 ± 6***	***115 ± 12***
	VW Jetta	***1.36***	***51 ± 12***	***24 ± 8***	***75 ± 15***
	Nissan Sentra	***1.27***	***98 ± 17***	***35 ± 10***	***133 ± 20***
	Mazda Protégé	0.81	87 ± 20	22 ± 10	109 ± 23
	Chevrolet Prizm	0.70	100 ± 23	24 ± 12	124 ± 26
	VW Golf/Cabriolet	0.44	54 ± 22	18 ± 13	72 ± 25
Subcompact cars (high-risk)	***Chevrolet Cavalier/Sunfire***	***4.98***	***146 ± 11***	***41 ± 6***	***187 ± 12***
	Ford/Mercury Escort/Tracer	***4.35***	***122 ± 10***	***37 ± 6***	***160 ± 12***
	Dodge/Plymouth Neon	***2.57***	***155 ± 15***	***40 ± 8***	***196 ± 17***
	Hyundai Elantra	0.82	119 ± 24	54 ± 16	173 ± 28
	Kia Sephia	0.75	157 ± 28	63 ± 18	220 ± 34
	Hyundai Accent	0.58	156 ± 32	31 ± 14	187 ± 35
	Mitsubishi Mirage	0.54	117 ± 29	63 ± 21	180 ± 36
	Acura Integra	0.43	142 ± 36	30 ± 16	172 ± 39
Compact cars	***Pontiac Grand Am***	***2.69***	***120 ± 13***	***40 ± 8***	***160 ± 15***
	Nissan Altima	***2.19***	***65 ± 11***	***44 ± 9***	***108 ± 14***
	Subaru Legacy/Outback	***1.22***	***74 ± 15***	***25 ± 9***	***99 ± 18***
	Mazda 626	***1.11***	***69 ± 15***	***28 ± 10***	***97 ± 18***
	Mitsubishi Galant	0.76	79 ± 20	33 ± 13	113 ± 24
Midsize cars	***Ford Taurus/Sable***	***6.47***	***76 ± 7***	***36 ± 5***	***112 ± 8***
	Toyota Camry	***5.51***	***42 ± 5***	***29 ± 5***	***72 ± 7***
	Honda Accord	***5.26***	***56 ± 6***	***28 ± 4***	***83 ± 8***
	Chevrolet Malibu	***2.36***	***81 ± 11***	***38 ± 8***	***119 ± 14***
	Chevrolet Lumina	***2.20***	***101 ± 13***	***44 ± 9***	***145 ± 16***
	Pontiac Grand Prix	***1.86***	***76 ± 13***	***33 ± 8***	***110 ± 15***
	Nissan Maxima	***1.59***	***55 ± 12***	***27 ± 8***	***82 ± 14***
	Buick Century	***1.45***	***81 ± 15***	***26 ± 8***	***107 ± 17***
	Dodge Stratus	***1.34***	***105 ± 17***	***41 ± 11***	***146 ± 20***
	Chrysler Sebring	***1.12***	***76 ± 16***	***41 ± 12***	***117 ± 20***
	Chevrolet Monte Carlo	0.92	121 ± 22	43 ± 13	164 ± 26
	Buick Regal	0.68	63 ± 19	25 ± 12	88 ± 22
Large cars	***Buick Lesabre***	***2.19***	***87 ± 12***	***33 ± 8***	***120 ± 15***
	Dodge Intrepid	***1.71***	***70 ± 13***	***44 ± 10***	***114 ± 16***
	Mercury Grand Marquis	***1.56***	***80 ± 14***	***43 ± 10***	***123 ± 17***
	Cadillac Deville/Fleetwood	***1.31***	***68 ± 14***	***41 ± 11***	***109 ± 18***
	Lincoln Town Car	***1.22***	***99 ± 18***	***47 ± 12***	***145 ± 21***
	Toyota Avalon	***1.02***	***41 ± 12***	***21 ± 9***	***62 ± 15***
	Pontiac Bonneville	0.85	82 ± 19	28 ± 11	111 ± 22
	Buick Park Avenue	0.77	67 ± 18	44 ± 15	111 ± 24
	Chrysler Concorde	0.69	51 ± 17	27 ± 12	78 ± 21
	Cadillac Seville	0.45	56 ± 22	36 ± 17	91 ± 28
	Lincoln Continental	0.42	29 ± 16	21 ± 14	50 ± 21

Table 3. Popular and most-popular 1997 to 2001 import luxury and sports car models analyzed, with millions of registration-years, risk-to-drivers, risk-to-drivers-of-other-vehicles, and combined risk, through 2001 per model. The most-popular models are shown in bold italics.

Vehicle type	Vehicle make and model	Millions of registration-years	Average risks and 95% confidence intervals: Risk-to-drivers	Risk-to-others	Combined risk
Import luxury cars	BMW 3 Series	0.72	73± 20	30± 13	103± 23
	Lexus ES300	0.69	29± 13	20± 11	49± 17
	Mercedes E Class	0.64	30± 13	17± 10	47± 17
	BMW 5 Series	0.51	40± 17	24± 13	63± 22
	Acura TL	0.45	29± 16	22± 14	51± 21
	Mercedes C Class	0.43	16± 12	9± 9	26± 15
	Infiniti I30	0.40	52± 22	22± 15	74± 27
Sports cars	Ford Mustang/Mustang II	1.90	132± 16	49± 10	181± 19
	Mitsubishi Eclipse	0.83	148± 26	58± 16	205± 31
	Chevrolet Camaro	0.62	309± 44	61± 19	370± 48
	Pontiac Firebird	0.42	270± 50	55± 23	325± 55
	Chevrolet Corvette	0.30	204± 51	30± 20	234± 55

Table 4. Popular and most-popular 1997 to 2001 minivan, SUV, and pickup truck models analyzed, with millions of registration-years, risk-to-drivers, risk-to-drivers-of-other-vehicles, and combined risk, through 2001 per model. The most-popular models are shown in bold italics.

Vehicle type	Vehicle make and model	Millions of registration-years	Average risks and 95% confidence intervals: Risk-to-drivers	Risk-to-others	Combined risk
Minivans	***Dodge Caravan***	***3.96***	***36 ± 6***	***37 ± 6***	***73 ± 8***
	Ford Windstar	***2.55***	***40 ± 8***	***38 ± 8***	***78 ± 11***
	Chevrolet Astro Van	***1.38***	***56 ± 13***	***59 ± 13***	***116 ± 18***
	Chevrolet Venture	***1.15***	***54 ± 13***	***36 ± 11***	***90 ± 17***
	Chrysler Town and Country	***1.05***	***32 ± 11***	***37 ± 12***	***69 ± 16***
	Mercury Villager	0.63	35 ± 15	32 ± 14	67 ± 20
	Honda Odyssey	0.60	17 ± 10	20 ± 11	37 ± 15
	Nissan Quest	0.55	22 ± 12	27 ± 14	49 ± 19
	GMC Safari	0.45	42 ± 19	69 ± 24	111 ± 31
	Oldsmobile Silhouette	0.43	59 ± 23	40 ± 19	99 ± 30
Sport-utility vehicles	***Ford Explorer***	***5.47***	***91 ± 8***	***61 ± 7***	***152 ± 10***
	Jeep Grand Cherokee	***3.52***	***61 ± 8***	***44 ± 7***	***105 ± 11***
	Ford Expedition	***2.95***	***55 ± 8***	***57 ± 9***	***113 ± 12***
	Chevrolet Blazer	***2.91***	***124 ± 13***	***51 ± 8***	***175 ± 15***
	Toyota 4-Runner	***1.67***	***92 ± 15***	***42 ± 10***	***134 ± 18***
	Chevrolet Tahoe	***1.65***	***74 ± 13***	***80 ± 14***	***154 ± 19***
	Jeep Cherokee	***1.62***	***63 ± 12***	***56 ± 12***	***120 ± 17***
	Chevrolet Suburban	***1.39***	***53 ± 12***	***67 ± 14***	***119 ± 18***
	Jeep Wrangler	***1.32***	***116 ± 18***	***49 ± 12***	***165 ± 22***
	Honda CR-V	***1.25***	***37 ± 11***	***29 ± 9***	***66 ± 14***
	GMC Jimmy	0.95	83 ± 18	42 ± 13	125 ± 23
	Nissan Pathfinder	0.92	61 ± 16	53 ± 15	115 ± 22
	Toyota RAV4	0.86	51 ± 15	26 ± 11	77 ± 19
	Isuzu Rodeo	0.78	86 ± 21	37 ± 14	124 ± 25
	Mercury Mountaineer	0.71	68 ± 19	55 ± 17	123 ± 26
	GMC Yukon/Denali	0.60	74 ± 22	77 ± 22	151 ± 31
Compact pickups	***Ford Ranger***	***4.25***	***120 ± 10***	***79 ± 8***	***199 ± 13***
	Chevrolet S-10/T-10	***2.80***	***163 ± 15***	***56 ± 9***	***219 ± 17***
	Toyota Tacoma	***2.00***	***113 ± 15***	***61 ± 11***	***174 ± 18***
	Dodge Dakota	***1.95***	***76 ± 12***	***113 ± 15***	***189 ± 19***
	GMC Sonoma	0.66	122 ± 27	53 ± 18	175 ± 32
	Mazda Pickup	0.49	101 ± 28	60 ± 22	160 ± 36
Full-size pickups	***Ford F-150***	***7.36***	***105 ± 7***	***95 ± 7***	***200 ± 10***
	Chevy/GMC C/K1500	***7.19***	***116 ± 8***	***94 ± 7***	***209 ± 11***
	Dodge Ram 1500	***3.51***	***88 ± 10***	***113 ± 11***	***201 ± 15***
	Ford F-250	***2.05***	***114 ± 15***	***173 ± 18***	***287 ± 23***
	Chevy/GMC C/K2500	***1.32***	***109 ± 18***	***128 ± 19***	***236 ± 26***
	Dodge Ram 2500	***1.01***	***101 ± 20***	***195 ± 27***	***296 ± 34***
	Ford F-350	***1.06***	***128 ± 22***	***231 ± 29***	***359 ± 36***
	Chevy/GMC C/K3500	0.52	107 ± 28	233 ± 41	340 ± 50
	Dodge Ram 3500	0.37	132 ± 37	305 ± 56	438 ± 67

The first analyses of this kind focused on driver fatality rates by vehicle type, based on estimated annual vehicle miles traveled, or VMT (Hollowell and Gabler, 1996; Gabler and Hollowell, 1998). Our analysis is similar, but examines model-dependent fatality rates by registered vehicles (as in IIHS, 2000; Farmer, 2001), and for both the drivers of the subject vehicle as well as drivers in vehicles with which it collides (as in Joksch et al., 1998). Our current results, which utilize more recent data and calculate risks using registrations rather than sales, differ only slightly from our previous results with respect to these changes (Ross and Wenzel, 2002; Wenzel and Ross, 2002; Levin, 2003).

Analysis of odometer readings from the National Accident Sampling System indicates that SUVs, minivans and pickups tend to be driven more miles per year than cars (Kahane, 2003). This finding is confirmed by preliminary analysis of odometer readings from California biennial emissions inspections. Calculating risk by annual miles driven, rather than by registered vehicles, would reduce the apparent risks of light trucks relative to those of cars, roughly by the amounts shown in Table 5. For example, import luxury cars have 153 fatalities and 3.8 million registration-years, resulting in a risk to their drivers of 40 (153 / 3.8 = 40). Since import luxury cars are driven 19% fewer miles than the average light-duty vehicle (Table 5), reducing their registration-years by 19% (to 3.1 million) would result in a risk of 49 (153 / 3.1 = 49), which is 23% higher than a risk of 40. Although some analysts prefer VMT as their measure of "exposure", or the denominator in calculating the risk, we present risks in terms of registered vehicles for two reasons. One, registration data are available by vehicle model and the interpretation of risk based on having a particular vehicle model is straightforward. And adding VMT adds a layer of estimation which makes the calculated risk less certain, and adds complication to its interpretation.

Table 5. Average odometer reading, percent difference, and effect on risks, by vehicle type. Odometer readings from 1999 California Smog Check records in Enhanced Smog Check areas (all urban areas of California except for the San Francisco Bay area).

Vehicle type	Average odometer reading of model year 1995 vehicle in 1999[1]	Percent difference in odometer reading relative to that of all light-duty vehicles	Approximate change in risks if estimated per annual VMT rather than per registered vehicle
Subcompact cars	62,628	0%	0%
Compact cars	63,235	1%	-1%
Midsize cars	59,367	-5%	5%
Large cars	54,254	-13%	15%
Import luxury cars	50,994	-19%	23%
Sports cars	58,900	-6%	6%
Minivans	67,168	7%	-7%
SUVs	62,859	0%	0%
Compact pickups	66,789	7%	-7%
1/2-ton pickups	71,293	14%	-12%
3/4-ton pickups	75,714	21%	-18%
1-ton pickups[2]	NA	21%	-17%
All light-duty	62,612		

[1] Odometer readings from emissions inspection and maintenance programs are not necessarily reliable because of transcription errors and odometer rollover.
[2] There were not enough 1-ton pickups in the Smog Check data to estimate their mileage; the mileage for 3/4-ton pickups was used for 1-ton pickups.

We also note an important difference between the "unconditional" risks presented here and some other analyses, and the "conditional" risks, that is, the risk given a serious crash, evaluated in other studies (Kahane, 1997; Joksch et al., 1998; Van Auken et al., 2003; Kahane, 2003). Conditional risk is typically calculated by dividing the number of driver deaths by the number of police-reported crashes in a certain category of vehicle. The category might be Camrys of certain model years, with the crashes being in a group of states that collect such information. Thus conditional risk addresses the ”crashworthiness“ of a vehicle and not its crash avoidance characteristics. We don't consider conditional risks here because the data are difficult to obtain and convert into a reliable dataset, and conditional risk analysis does not consider the effect of vehicle design on crash avoidance. A major limitation of the unconditional risks we calculate here is that unconditional risk incorporates driver behavior effects which we can only partially account for.

3. Risks by Vehicle Type and Model

The risks to a vehicle's own driver and to drivers of other vehicles are shown by vehicle type in Figures 1 and 2. Both figures present the same information, but in a different format. Figure 1 stacks the two risks on top of each other and allows easy comparison of the combined risk, while Figure 2 plots the risk-to-drivers on the x-axis and the risk-to-drivers-of-other-vehicles on the y-axis. The diagonal lines in Figure 2 showing combined risks of 110 and 130 illustrate the concept; vehicle types above and to the right of a line have a higher combined risk, while types below and to the left have a lower combined risk. Figure 1 also shows the risks of the 3/4-ton and 1-ton pickup trucks.

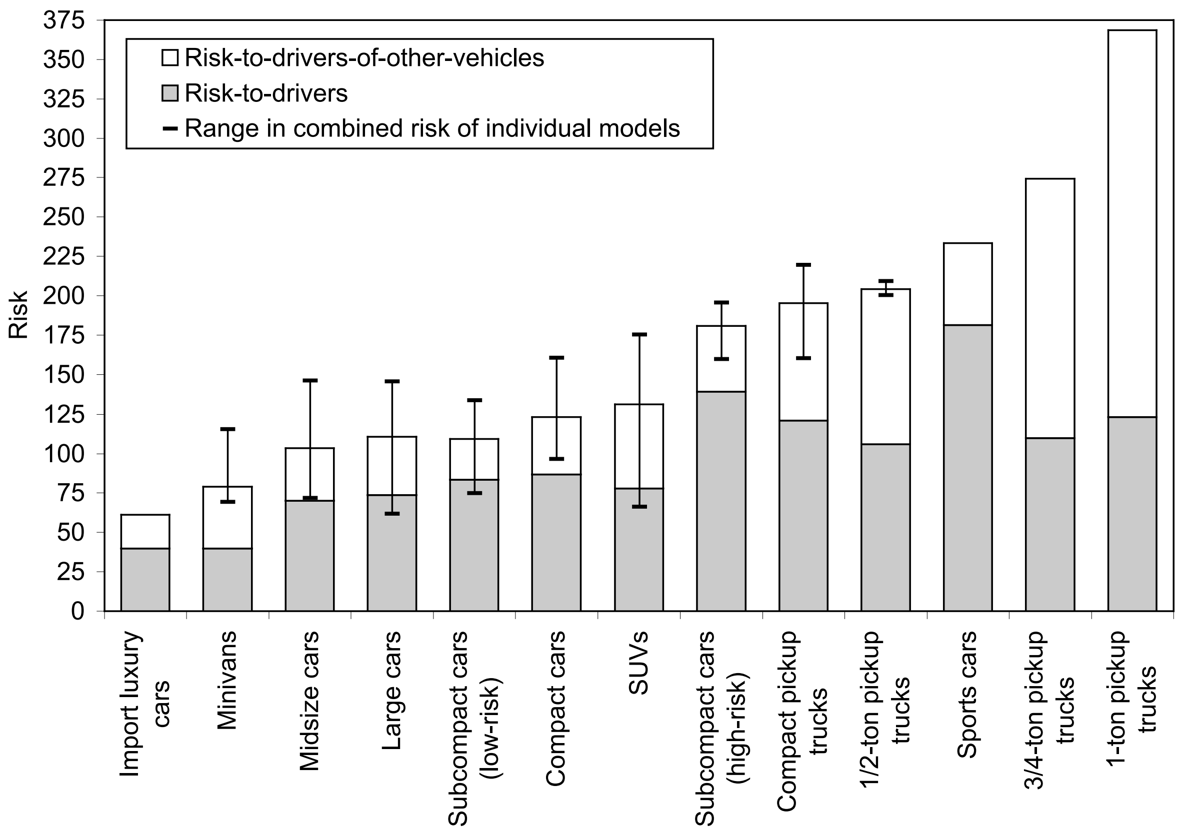

Figure 1. Risk-to-drivers and risk-to-drivers-of-other-vehicles, by vehicle type. The sum of the two risks is the combined risk. Lines and whiskers represent the range in risks of the most-popular vehicle models of each type. Differences in risk between types that are less than about 10% are not statistically significant. Data are for model year 1997 to 2001 vehicles through 2001.

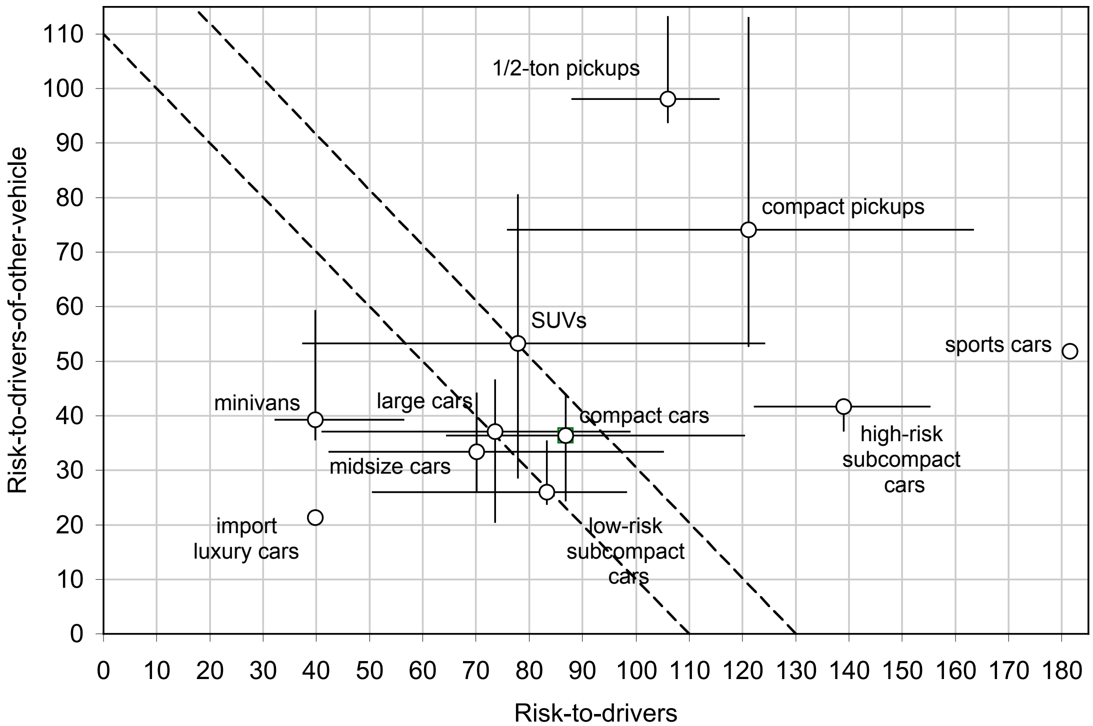

Figure 2. Risk-to-drivers and risk-to-drivers-of-other-vehicles, by vehicle type. Dashed diagonal lines illustrate combined risks of 110 and 130. Solid lines represent the range in risks of the most-popular vehicle models of each type. Differences in risk between types that are less than about 10% are not statistically significant. Data are for model year 1997 to 2001 vehicles in crashes through 2001.

Figure 3 presents the two risks as a scatterplot for the most-popular models. Because of the limited numbers of fatalities for each vehicle model, differences in risks by vehicle model that are less than roughly 15%, may not be statistically significant. Tables 2 through 4 include the two types of risk, as well as combined risk, and the 95% confidence interval for each of the popular vehicle models; the most-popular models shown in Figure 3 are indicated in bold italic type in Tables 2 through 4. The confidence interval in the tables is based on the standard error of the risk for a vehicle model. The standard error is estimated as:

$$\{[D (1- D/n)] ^ 0.5\} / n$$

where D = the number of drivers of the model who were killed and n = the registration years of the model. This expression is typically meaningful as the standard error of a vehicle model if there were no major changes in a model's design over the 5-year period analyzed, which is the case for almost all of the popular models shown. The range in risk among the most-popular models within a vehicle type is larger than the statistical uncertainty of the average risk for each vehicle type; therefore, we show the range in combined risk among models within each vehicle type in Figure 1 and the range in the two risks among models with each vehicle type in Figure 2, rather than the statistical uncertainty by vehicle type.

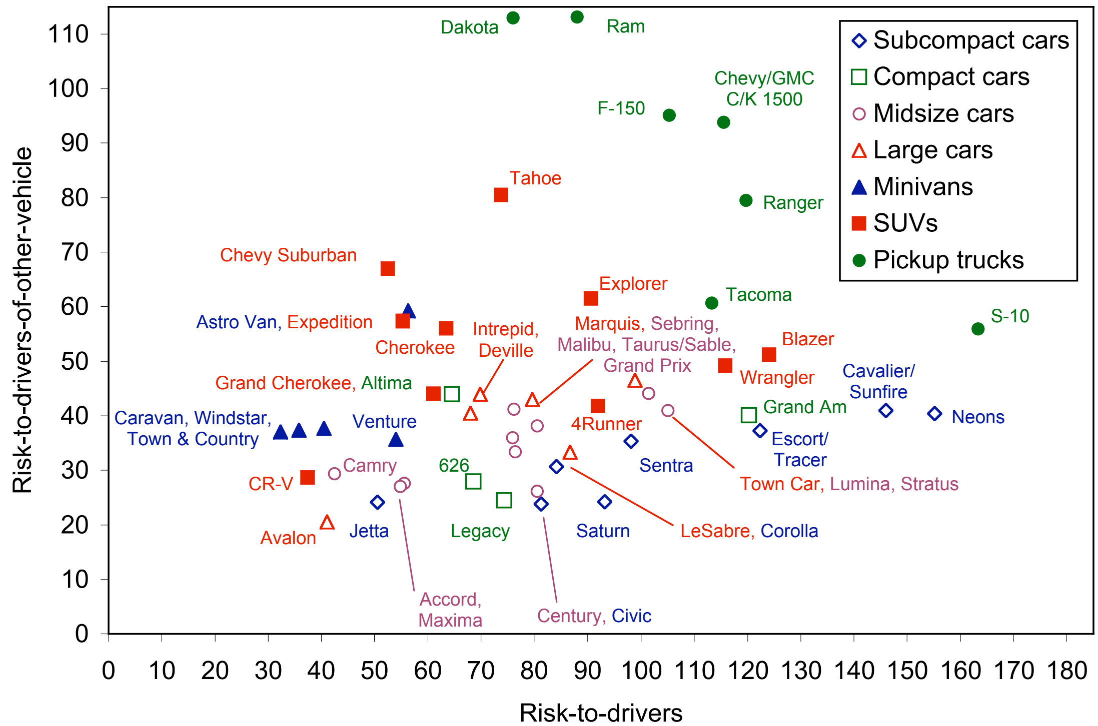

Figure 3. Risks of the most-popular vehicle models. The pickup models shown are compact and 1/2-ton pickups only. Differences in risks between models that are less than about 20% are not statistically significant. Data are for model year 1997 to 2001 vehicles in crashes through 2001.

Many results can be drawn from these three figures:

Minivans. Of the major vehicle types, only minivans (with the exception of the Astro Van) form a compact group with similar risks.

Cars. There is a wide range in the risk-to-drivers of car models, ranging from about 40 on the left in Figure 3 (Avalon and Camry) to 155 on the right (Neon). The risks-to-drivers of sports cars are even higher, while those of import luxury cars are the lowest (shown in Figures 1 and 2 but not in Figure 3). Subcompact models have perhaps the widest range in the risks to drivers (from Jetta with 51 to bottom-of-the-market cars like Neon with its 155). The lowest-risk cars are from Japanese and German firms (Avalon, Camry, Jetta, Accord, and Maxima, as well as the import luxury cars).

SUVs. The average SUV has a risk-to-driver similar to that for cars. They are not safer for their drivers than cars, in spite of the popular belief that weight increases safety. Among most-popular vehicles, no SUV has as low a risk to its drivers as the safest cars or minivans. While most SUVs are comparable to cars in risk to their own drivers, they are much more dangerous than cars to drivers of other vehicles. The most-popular SUVs have nearly twice the risk-to-others of cars, as seen on the vertical-axis in Figures 2 and 3. While the risk-to-others ranges from 20 to 50 for the cars in Figure 3, for SUVs it ranges from 44 (Grand Cherokee and 4-Runner) to 80 (Tahoe).

<u>Pickup trucks</u>. Most compact and 1/2-ton pickup trucks pose higher risks to their own drivers than most cars and SUVs; one, the Chevy S-10, has a particularly high risk at over 200, shown in Figure 3. (The figure shows only compact and 1/2-ton pickups. Larger pickup models are discussed in connection with Figure 9 below.) And they are by far the most dangerous to drivers of other vehicles. The risk-to-others imposed by pickup trucks is high, and increases dramatically as their size increases, as shown in Figure 1.

4. Discussion

<u>Minivans</u>. Although minivans have unibody structure rather than the stiff frames of pickup trucks (as discussed below), as a group they tend to have higher risk-to-others than most cars. This higher risk-to-others is likely due to the higher mass and front end, relative to cars.

<u>Cars</u>. There is a wide range in risk-to-driver of cars, with risk appearing to increase as mass decreases. However, mass alone is only a modest predictor of risk in all types of crashes. Resale value at 5 yeas of age or so is the best single predictor we have found for risk-to-driver of cars (Figure 4). Resale value is the 1998 model-year retail price as of January 2003 for cars in excellent condition (Kelley Blue Book Co., 2003). Of course resale value depends in part on owner/driver preference and thus on driver ”behavior“. But the same is true of variables like vehicle mass, which have the appearance of being objective vehicle characteristics while also involving driver behavior. Another good predictor of risk-to-driver of cars is the country of origin paired with mass (Figure 5). Here mass is the inertial weight, or curb weight plus 300 lbs; curb weights are provided in FARS for each vehicle based on the decoded vehicle identification number in FARS. For cars with roughly the same mass, Figure 5 indicates that the risk-to-driver

can vary greatly by manufacturer; or, for a given level of risk, Japanese/German cars are about 1000 lbs lighter than US/Korean cars. Most of the popular, as well as the most-popular, car models in Tables 2 and 3 are included in Figures 4 and 5 to extend the range of risks in the figures. In order to minimize the effect of driver behavior in Figures 4 and 5, we exclude 19 models whose risks are unduly influenced by driver behavior (more than 30% young male driver fatalities, which includes all sports cars as well as the Jetta and Civic, or more than 40% elderly driver fatalities). The figures suggest that there are different vehicle characteristics that are both relatively good and plausible in predicting risk; mass may not be fundamentally associated with the risk-to-driver in all types of crashes.

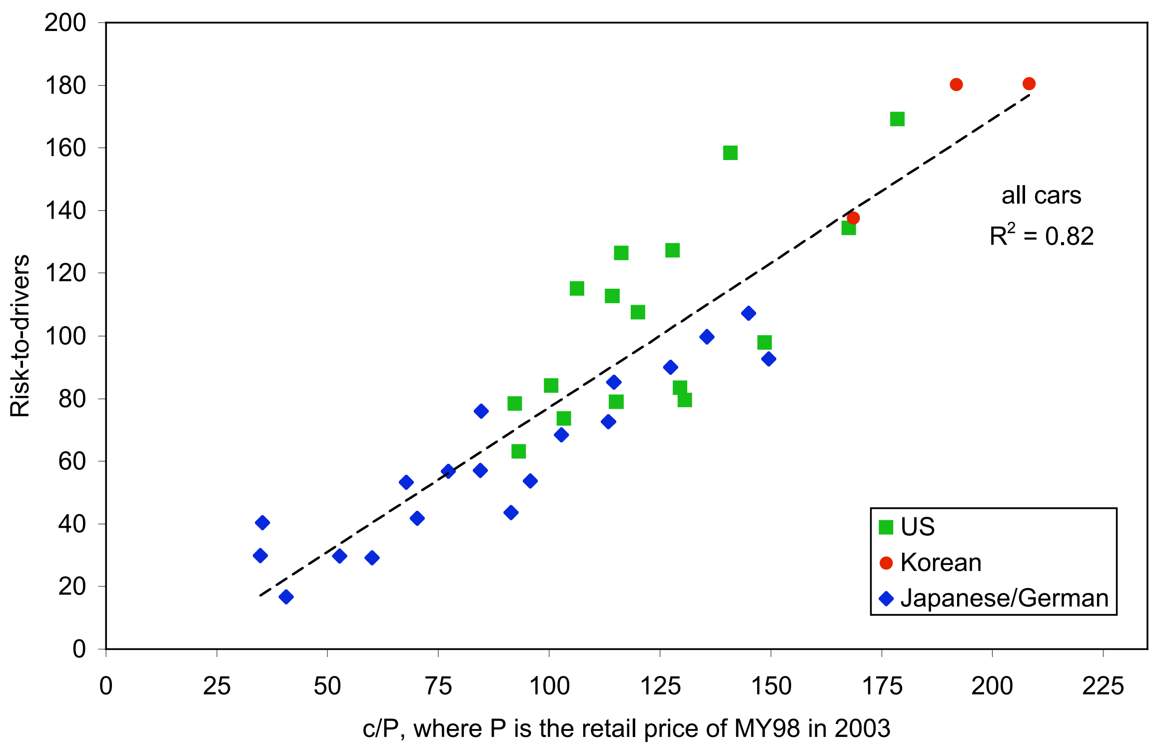

Figure 4. Relationship between risk-to-drivers of cars and the reciprocal of the resale value of five year old cars, by car manufacturer and model. Differences in risks between models that are less than about 20% are not statistically significant. Fatality data are for model year 1997 to 2001 vehicles in crashes through 2001, while resale value is the retail price of MY98 car in 2003. US cars include models with Chrysler/Dodge/Plymouth, Ford/Lincoln/Mercury, and General Motors nameplates.

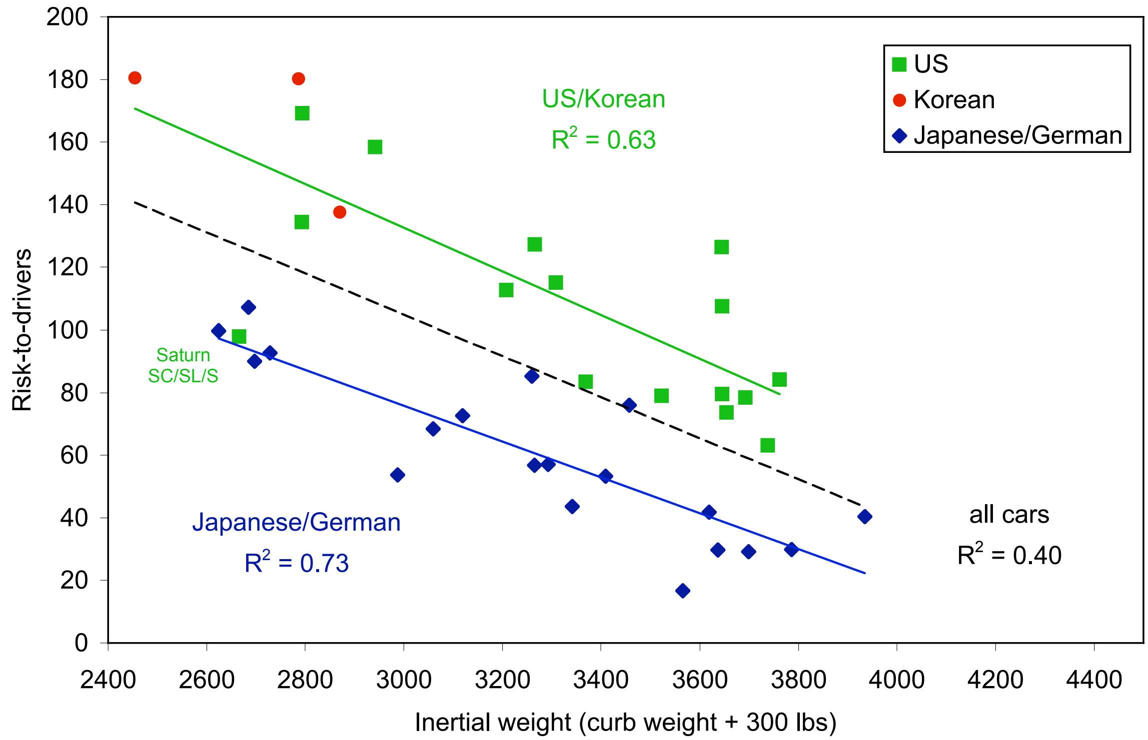

Figure 5. Relationship between risk-to-drivers of cars and inertial weight, by car manufacturer and model. Differences in risks between models that are less than about 20% are not statistically significant. Fatality data are for model year 1997 to 2001 vehicles in crashes through 2001. US cars include models with Chrysler/Dodge/Plymouth, Ford/Lincoln/Mercury, and General Motors nameplates.

This is important because improvement of fuel economy is a major goal for designers of new vehicles, and reduction of mass has major potential for improving fuel economy. Much has been made in the past about the high risk of low-mass cars in certain kinds of collisions. Figures 4 and 5 show there are plausible explanations that apply broadly and are statistically attractive, suggesting that mass may not be fundamental to risk-to-driver. Of course, such correlations do not prove that mass reduction can be safely adopted as a general strategy. In our view, the issue needs clarification through more careful analysis of crash data.

<u>SUVs</u>. Risks for an expanded group of popular SUVs for more recent model years 1999-2001, with fatal crashes through 2002, are shown in Figure 6. In order to include some newer models, models with relatively low registrations are shown; however, all models in the figure have at least 15 driver fatalities, and 8 fatalities to other drivers in other vehicles. (We cannot adjust the

risks for the newer models based on vehicle attrition over time, so the risks shown in Figure 6 are slightly higher than shown elsewhere.) The riskiest SUVs in Figure 6 (ranging from 120 to 150) have almost as high risk-to-driver as the highest-risk subcompact cars in Figure 3 (note that the high-risk SUVs Blazer and Montero Sport have curb weights of approximately 4000 lbs, while the much smaller high-risk subcompact cars have curb weights of only 2600 lbs). For the relatively small, or ”compact“, SUVs, the pattern is similar to that for subcompact cars, where bottom-of-the-market cars have much higher risks than those of higher quality subcompacts (Figure 1). Some of the smaller SUVs (Tracker, Sportage) have very high risks, while others (like CR-V and RAV4) have low risks.

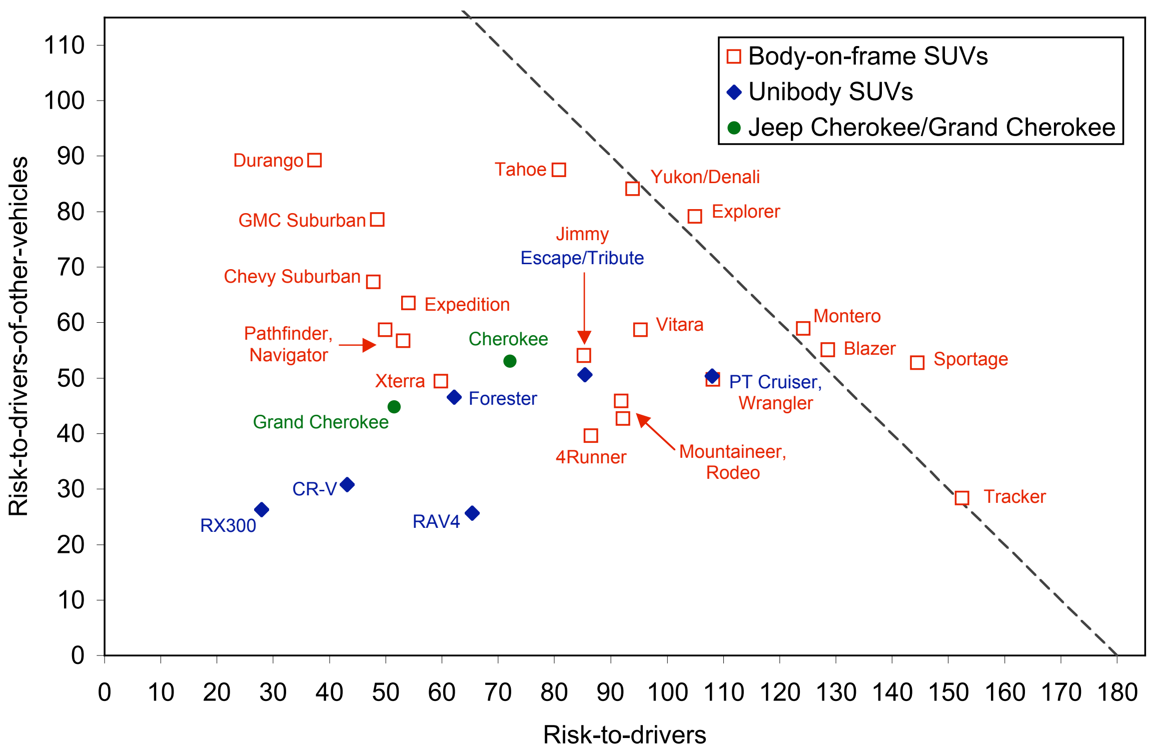

Figure 6. Risks of popular SUV models by design type. The diagonal line illustrates a combined risk of 180. Differences in risks between models that are less than 20% are not statistically significant. Data are for model year 1999 to 2001 vehicles through 2002.

Most SUVs have a ”body-on-frame“, or truck-based, structure in which the upper body of the vehicle is attached to a pickup truck chassis, which involves two heavy frame rails running the length of the vehicle. In many cases these rails are high enough to override the massive or protective parts of cars. Body-on-frame structure contrasts with unibody structure, where the body as a whole, including the outside surface panels, gives the vehicle its strength, as with cars. The average body-on-frame SUV has substantially higher risks to its drivers and others (83 and 65, respectively) than the average unibody SUV (55 and 36), as shown in Table 6. The Jeep Cherokees are called out separately in the figure and table because they utilize unibody construction but retain the heavy frame rails of conventional pickups.

Table 6. Risks of SUVs by body type.

SUV type	Risk-to-drivers	Risk-to-others	Combined risk
Truck-based SUVs	83	65	147
Jeep Cherokees	58	48	106
Unibody SUVs	55	36	91

Body-on-frame was an inexpensive and quick-to-implement SUV design in the early 1990s (Bradsher 2002, pages 56, 59), and, like compact pickups, results in a relatively tall and narrow profile that is prone to rollover. Table 7 indicates that the risk-to-driver associated with rollovers is 10 to 25 for most cars and minivans, but roughly 40 to 60 for pickups and body-on-frame SUVs. The risk-to-driver associated with rollovers in the two unibody SUV models with substantial crash records (CR-V and RAV4) is only 18.

Table 7. Risk-to-driver in one-vehicle rollover crashes compared to total risk-to-driver, by vehicle type. Data are for model year 1997 to 2001 vehicles in crashes through 2001.

Vehicle type	Risk-to-drivers in one-vehicle rollovers[1]	Risk-to-drivers in all crashes	Percent from rollovers
Subcompact cars	25	111	22%
Compact cars	25	87	29%
Midsize cars	16	70	22%
Large cars	12	74	16%
Import luxury cars	10	40	25%
Sports cars	62	182	34%
Minivans	9	40	23%
SUVs	41	78	53%
Car-based SUVs[2]	*18*	*50*	*35%*
Compact pickups	51	121	42%
1/2-ton pickups	35	88	40%
3/4-ton pickups	58	110	53%
1-ton pickups	52	123	42%
All LDVs	32	97	33%

[1] includes both first event and subsequent event rollovers.

[2] RAV4 and CR-V

Some of the newer unibody SUV models (sometimes called car-based or crossover SUVs), such as the Lexus RX300 and Honda CR-V, have very low risks, both to their drivers and to drivers of other vehicles. It is tempting to associate these low risks with the unibody design, especially its low rollover characteristic and the relatively soft front of a unibody structure, although such a general interpretation must be regarded as preliminary because so few manufacturers and models are involved. At this time, we can say that as a group their risks are lower than those of typical body-on-frame SUVs.

Many have documented that the fatality rate in a car when struck in the side by a SUV or pickup truck is several times that when struck in the side by another car (Hollowell and Gabler, 1996; Gabler and Hollowell, 1998, Joksch 1998). We show in Figure 7 that the pattern of risks of truck-based SUVs is closely related to that of the pickups on which they are based, suggesting that common design features in the pickup and SUV versions play a critical role. For example, the S-10 pickup has the highest risk to its drivers, and a relatively low risk to drivers in other vehicles, of the pickups shown. Similarly, the Blazer SUV, which is based on the S-10 body, has the highest risk to its drivers of all SUVs shown.

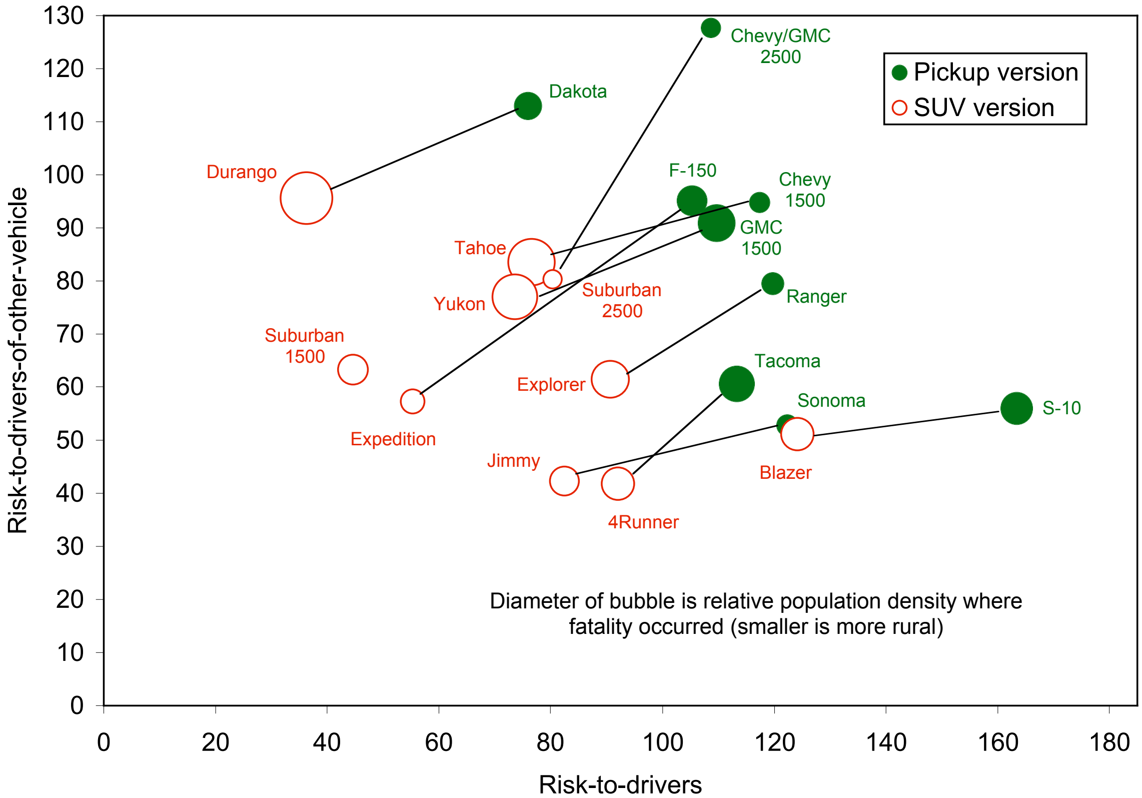

Figure 7. Risks of each popular SUV coupled with risks of the pickup on which it is based. Differences in risks between models that are less than 20% are not statistically significant. Data are for model year 1997 to 2001 vehicles in crashes through 2001.

One motivation for our analysis of traffic deaths by vehicle model has been to explore connections between traffic deaths and fuel consumption (and the associated air emissions, especially carbon dioxide). Major increases in fuel economy in the future will be achieved by redesign of vehicles, and not by new-vehicle buyers shifting down in mass/size among today's vehicles. Since mass and other load factors play a critical role in the energy required to move vehicles, vehicle bodies and powertrains will likely be redesigned in ways that reduce the load while achieving other benefits. Several design strategies would enable reducing mass in order to improve fuel economy, without a comparable reduction in vehicle size (Ross and Wenzel, 2001). In particular, the unibody SUV is a design which appears to offer major advantages in safety, with both risk-to-driver and risk-to-others being substantially lower, at least in preliminary fatality data.

The initial unibody SUV models have two fuel-economy advantages compared to that of typical body-on-frame SUVs: their structures are lighter for a given interior volume, and their powertrains are more efficient. The two fuel-economy benefits are comparable. The combined benefit is a fuel economy over 30% higher for a given interior volume (Figure 8).

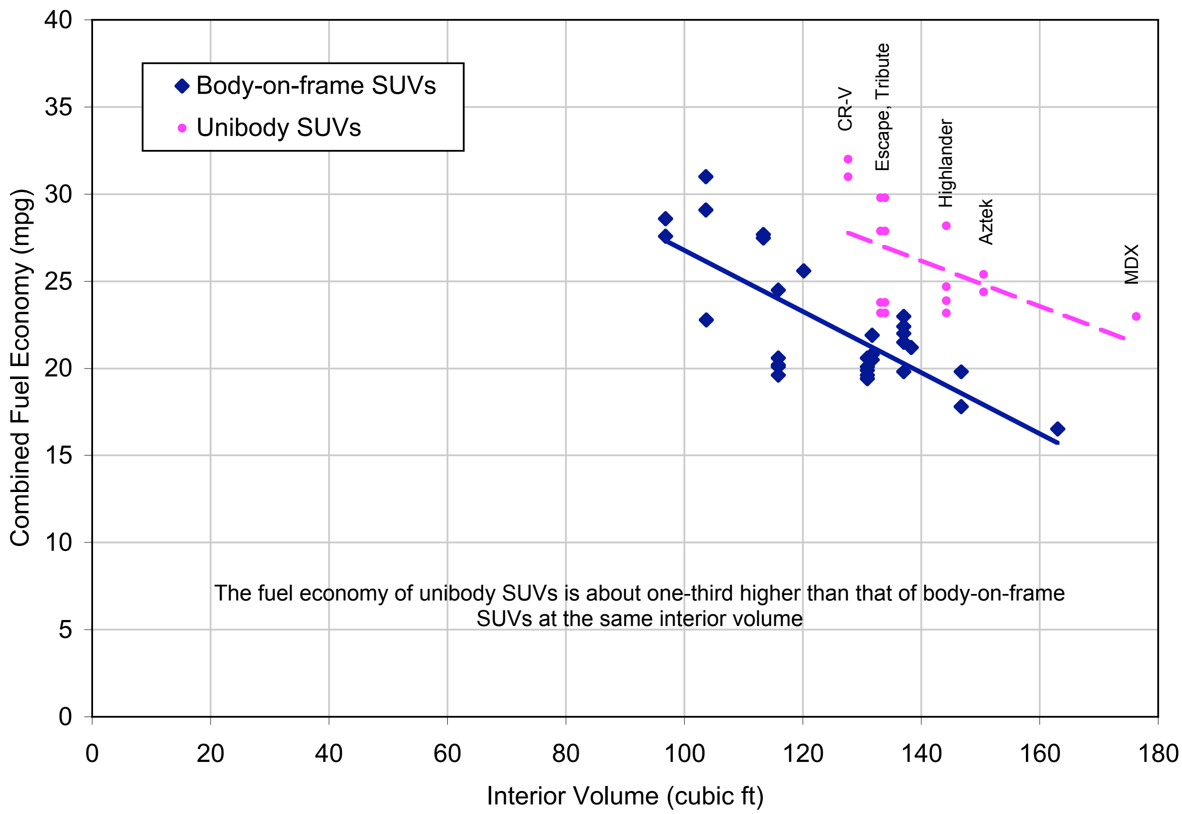

Figure 8. Fuel economy and interior volume (passenger plus cargo) of body-on-frame and unibody SUVs , model years 2001 through 2004.

One limitation with unibody SUVs is that they do not have the same towing capacity as the body-on-frame SUVs. And some drivers prefer the view of the road that the higher seating of a body-on-frame SUV provides. However, many unibody SUVs provide the same amenities (four-wheel drive, road clearance, and large cargo space) that appeal to most buyers of body-on-frame SUVs, while reducing risk both to their drivers and to drivers of other vehicles.

<u>Pickup trucks</u>. In Figure 9 the two risks are shown for the most-popular models in the four size categories of pickups. The pattern of risks is highly regular with respect to the size/capacity of the truck: for most pickups, the risk-to-driver is between 100 and 130, higher than the average for cars and SUVs. With one exception, the Dodge Dakota, the compact pickup trucks tend to

have the same or higher risk to their drivers than the full-size pickups. The risk-to-others increases sharply with pickup size/capacity, from about 75 for most compact pickups to over 220 for the full-size 1-ton pickups. Of all light-duty vehicles, the 1-ton pickups (Dodge Ram 3500, Ford F-350, and Chevrolet/GMC 3500) are the most dangerous to others on the road. And that's on a per-truck basis; one might have thought that crashes with other vehicles would be rare on rural roads. To indicate the scale, in Figure 9 we also show the risks of a Camry, the most popular car now on the market.

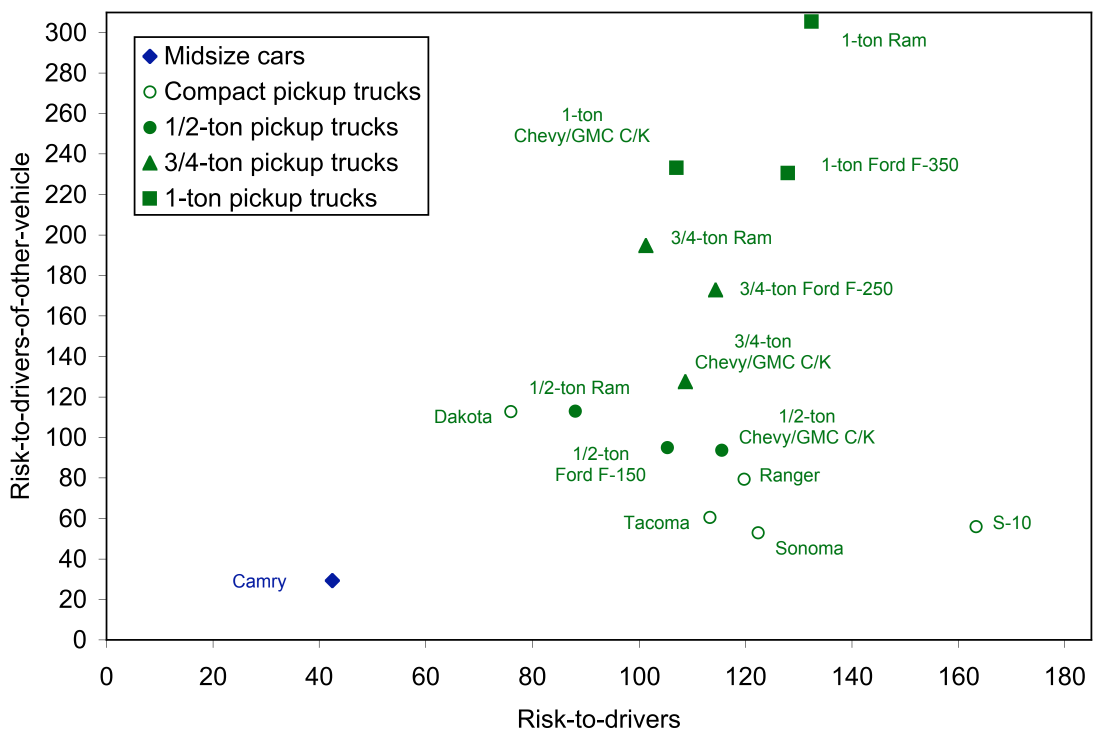

Figure 9. Risks of popular pickup models, by rated capacity. Differences in risks between models that are less than 20% are not statistically significant. Data are for model year 1997 to 2001 vehicles through 2001. Note that the scale for risk-to-drivers-in-other-vehicles is much higher than that in other figures, and higher than the scale for risk-to-drivers.

The average 1-ton pickup kills about ten times more people in other vehicles than an average Camry. Very roughly, with its combined risk of about 370, during its life an average 1-ton pickup has a nearly 1% expectation of killing someone in a traffic crash. (That is, assuming a combined risk of 370 driver fatalities per year per million vehicles, times 1.5 average occupants per vehicle, times average truck life of 14 years equals an expectation of 0.008 fatalities, nearly 1%.) It's not hard to think of ways for regulators and manufacturers to reduce this risk. For example, an energy-absorbing underride guard below the bumper could be installed (Berg et al. 2003) that could be designed to be in place at road speeds, and to rise up for off-road use. While this would not be a trivial add-on, the lives lost because of pickup aggressivity are not trivial either.

5. Driver behavior

Driver behavior and vehicle design both play major roles in the risk of death in traffic crashes. (To repeat, ”driver behavior“ is shorthand for how, where, and when the vehicle is driven and how it is maintained.)

Several behavioral characteristics have been identified as associated with unusually high risk, although the quality of data is often poor. Certain state crash databases, which contain information on both vehicle model and driver characteristics, have been used to account for driver characteristics when analyzing fatality rates (Kahane, 1997; Joksch et al., 1998; Van Auken and Zellner, 2002; Van Auken et al., 2003; Kahane, 2003). In some analyses, only a subset of vehicles, deemed to not be at fault in the collision, are used as the exposure or denominator when calculating risk. We do not use the more sophisticated approach with state crash data because only a few states collect the vehicle identification number necessary to determine the vehicle model; utilizing crash data from only a few states could bias the relationships between fatality rates and driver characteristics by vehicle type and model. We examine three major behavioral factors with good data and strong risk associations: driver age/sex, a measure of illegal driving, and urban/rural driving.

Young male drivers are associated with much higher risk than others (Kahane 1997, figure 1-1). Table 8 shows the fraction of fatalities that were young men or elderly drivers by vehicle type. There appears to be a positive relationship between the fraction of young male drivers and the risk-to-drivers by vehicle type. For instance, the risky sports cars have the highest fraction of young males, while the safe minivans have the lowest. On the other hand, very few elderly drive sports cars, while the relatively safe large cars have the highest fraction of elderly drivers. The relationship involving young males is less strong when one considers vehicle models. For instance, the safe Civic and Jetta have relatively high fractions of young male drivers (31% and 26%, respectively), while the riskiest SUV, the Blazer, has the same fraction of young male drivers as the average SUV (16%). In any event, SUVs, pickups, and the major car types have about the average number of young male and elderly drivers; therefore accounting for these risky drivers would only explain a small part of the difference we observe in the risk-to-drivers of each vehicle type. However, more subtle, and perhaps unquantifiable, differences between drivers may account for differences in risk (Bradsher 2002, pages 106, 108).

Table 8. Risk-to-drivers, fraction of driver fatalities that are young males or elderly, bad driver rating, and average population density in counties where fatalities occurred, by vehicle type. Data are for model year 1997 to 2001 vehicles in crashes through 2001.

Vehicle type	Risk-to-drivers	Fraction of driver fatalities that are: Young males (< 26 years old)	Elderly (> 65 years old)	Bad driver rating* (higher rating for worse drivers)	Average population density in county where fatality occurred
Import luxury cars	40	21%	12%	0.47	643
Minivans	40	6%	23%	0.19	391
Midsize cars	70	16%	24%	0.36	429
Large cars	74	8%	51%	0.24	357
Low-risk subcompact cars	83	21%	14%	0.43	548
Compact cars	87	23%	12%	0.46	420
SUVs	78	16%	7%	0.42	333
High-risk subcompact cars	139	21%	12%	0.50	375
Compact pickups	121	30%	13%	0.52	259
1/2-ton pickups	106	22%	10%	0.48	232
Sports cars	182	40%	1%	0.76	560
3/4-ton pickups	110	16%	11%	0.45	142
1-ton pickups	123	15%	5%	0.41	181
All light-duty vehicles	97	20%	15%	0.40	356

* Bad driver rating based on alcohol or drug involvement, driving without valid license, or reckless driving in current crash, as well as driving record in the last three years (ala Kahane 2003).

Table 8 also shows a measure of illegal driving, based on data included in FARS. The "bad driver rating" is based on alcohol or drug involvement, driving without a valid license, or reckless driving in the current crash, as well as the driver's driving record in the last three years (Kahane 2003). The values shown are for all drivers in fatal crashes; drivers that survive fatal crashes tend to have a lower bad driver rating (0.36 for all light-duty vehicles) than drivers that are killed (0.47). The table indicates that bad driver rating correlates rather well with the fraction of fatalities that are young males ($R^2 = 0.81$), for vehicle types. Sports cars have the highest bad driver rating and young male fatalities, while minivans and large cars have the lowest. Pickup drivers may be only slightly worse drivers than those of the average car: they appear to be much worse than minivan and large car drivers, but much better than sports car drivers.

Rural driving is much more dangerous than urban, due to poor road design, and lack of signage, lighting and enforcement. Analysts often identify rural and urban crash sites by the jurisdiction-based rural/urban road designation in FARS, which suffers from the fact that many urban-designated roads are highly rural in character. We instead define crash sites by the population density of the county in which the crash occurred. This designation is certainly not perfect, but it has the advantage that it is a continuous measure, and that it powerfully discriminates highly rural roads by their risk. Across the US, per capita traffic deaths by county vary by a factor of ten, from the densest to the least dense county (broad averaging is required for low-density counties to obtain suitable death statistics.) Table 8 indicates that import luxury, sports, and low-risk subcompacts tend to be driven more in dense (more urban) areas than pickups. And fatalities in SUVs tend to occur in areas with the same population densities as most other car types.

It is essential to consider how driver behavior by vehicle type (and model) may affect each of the above findings:

<u>Minivans</u>. Minivans are often driven as a family vehicle. For example they tend to carry children much more often than other vehicle types, as shown in Table 9 (the largest SUVs, such as Suburban and Expedition, tend to carry children as often as minivans). Driver care is undoubtedly important in the low risk-to-drivers of minivans.

Table 9. Number of children (<16 years) per vehicle in FARS. Data are for model year 1995 to 2001 vehicles in crashes through 2001.

Vehicle type	Average	Range among most popular models (SUV models in italics are outliers)
Subcompact car	0.21	0.13 (Civic) to 0.28 (Neon)
Midsize car	0.19	0.11 (Regal) to 0.26 (Malibu)
Large car	0.12	0.07 (Lesabre) to 0.25 (Intrepid)
Minivan	0.62	0.52 (Voyager) to 0.69 (Astro Van)
SUV	0.32	0.10 (Wrangler) to 0.33 (Explorer); *0.59 (Expedition), 0.73 (Suburban)*
Compact pickup	0.10	
1/2-ton pickup	0.15	
3/4-ton pickup	0.13	
1-ton pickup	0.13	

Cars. Some of the large range in the risk to car drivers is explained by differences in the drivers (risky drivers in sports cars, cautious drivers in import luxury cars), and some by differences in the vehicles themselves. Subcompact car models include cheap bottom-of-the-market models as well as more expensive (although not luxury) models that are carefully designed and built. And those widely different cars *may* tend to attract widely different drivers, which probably explains in part the higher risk-to-drivers of the bottom-of-the-market subcompacts. As shown in Figure 5, Japanese and German (not including Daimler/Chrysler) cars of a given mass consistently have lower risk than US cars produced by GM, Ford and Daimler/Chrysler. These lower risk cars tend to be more expensive and to depreciate more slowly than the US cars of the same type, so "quality" is likely to be a factor in their risk ratings. But some of that difference in risk is likely to be associated with "driver behavior". Japanese and German cars may tend to appeal to people who pay more attention to vehicle safety and reliability; perhaps they live in neighborhoods where that is a topic of discussion, or read magazines that rate vehicle quality before they purchase. We did not find a positive correlation between the lower-risk Japanese/German cars and young male drivers, bad drivers, or rural driving; however, risk may correlate with other, more subtle differences between drivers. One would think that unfamiliarity with a rental car might explain the higher risks in certain car models than in others; however, the fraction of drivers killed in crashes in a state different from where the car is registered is slightly lower for the high-risk subcompact cars (8%) that rental agencies use than for the low-risk subcompacts (11%).

SUVs. One may speculate that where safety-related marketing of European cars may have attracted safer drivers, most SUVs have not been sold as requiring the special care in driving that trucks call for. (Bradsher 2001) NHTSA does require that SUVs with a wheelbase of 110 inches or less have a label on their visor warning about their propensity to roll over if not driven with care; the regulation was recently changed to make the warnings more prominent (Federal Register, 1999). However, manufacturers do not go to special lengths to educate drivers of their SUVs of the risks they face, and no education is provided on the risk SUVs and pickups impose on others.

In connection with Figure 4 on SUVs, we tentatively interpret the relatively low risk of unibody SUVs as due to vehicle design. But, as with cars, some of the low risk may be associated with who drives those particular models.

Pickup trucks. In practical terms, the risk-to-others of pickups is primarily a vehicle design issue, and does not appear to be a matter of driver behavior. However, some of the risk to pickup drivers may be due to their heavy use on rural roads, which are less safe than urban/suburban roads (National Safety Council 1994, NHTSA 2001).

We show in Figure 7 that the risks of truck-based SUVs are closely related to those of the pickups on which they were based, suggesting that design features in common play an important role. In every case, however, the risk in the SUV is much less than in the corresponding pickup, which may be explained in part by pickups being driven in somewhat more-rural areas and/or the SUV being used more as a family vehicle. The diameter of the symbols in the figure corresponds to the average population density of the counties where the fatalities occurred. The figure indicates that the population density where fatalities in pickups occur is the same or somewhat lower (i.e. more rural) than the density where fatalities in their corresponding SUVs occur.

Table 8 indicates that the fatalities in pickups are indeed occurring in more rural areas (i.e. those with lower population densities) on average than the deaths in SUVs, minivans, and cars. But how much does the tendency of pickups to be driven on rural roads increase the associated risk?

We analyze fatality rates in a state, California, for which we have registration information by county as well as by vehicle model. Table 10 shows the vehicle registration-years, driver fatalities, average population density, risk-to-drivers and risk-to-others in California urban and rural counties, and statewide, by vehicle type. The two types of risk are dramatically higher for crashes in rural counties as opposed to those in urban counties, for all vehicle types. However, the large number of pickups registered in rural counties (37%, as opposed to only 20% for cars and SUVs), and the high risk on rural roads as shown in Table 10, does not increase the statewide risk to pickup drivers relative to that of car drivers (93 vs. 91). In fact, the risk to car drivers on rural roads is even higher than that of pickup drivers on rural roads (210 vs. 149), which may well be caused by the high risk posed by light trucks to cars.

Table 10. Registration-years, driver fatalities, and risk-to-drivers in California urban and rural counties, by vehicle type. Data are model year 1995 to 1999 vehicles registered as of October 1999, for crashes through 2002. Urban counties are Alameda, Contra Costa, Los Angeles, Marin, Orange, Sacramento, San Bernardino, San Diego, San Francisco, San Mateo, Santa Clara, and Ventura; all other California counties are considered rural.

	Cars			SUVs			Pickups		
	Urban	Rural	Total	Urban	Rural	Total	Urban	Rural	Total
Registration-years	14.4 80%	3.7 20%	18.0	3.5 79%	0.9 21%	4.4	2.8 63%	1.6 37%	4.4
Driver fatalities	872 53%	770 47%	1,642	153 48%	179 56%	320	167 41%	238 59%	405
Density[1]	1,898	165	1,115	1,807	139	984	1,360	154	674
Risk-to-driver	61	210	91	44	179	73	60	149	93
Risk-to-others	29	69	37	45	142	66	67	147	96

[1]Average population density in county in which fatality occurred, weighted by driver fatalities.

Table 10 also suggests that part of the low risk of import luxury and low-risk subcompact cars may be the result of them being driven mostly in urban areas (as shown in Table 8). On the other hand, the high-risk sports cars also tend to be driven in more urban areas.

6. Conclusions

We have shown that the most-popular recent car models driven in the US exhibit widely different levels of risk-to-driver, ranging over a factor of five, and of risk-to-others, ranging over a factor of two. Some of the differences can be ascribed to dangerous driver behavior, three components of which we examine: rural driving, a pattern of illegal driving, and driving by the young and old. Rather than quantifying the roles of these three components in detail, we show that little of the observed risk by vehicle model can be directly attributed to them: although they probably explain the high risks of certain sports cars, and the low risks of minivans, the components of driver behavior that we examine do not explain much of the variation in risks in other types of cars.

We conclude that most of the range in risk in cars must be attributed to vehicle design and to difficult-to-quantify driver characteristics and/or behavior. Design encompasses gross physical features like mass and size, general quality of design and manufacture, and specific safety features. Mass and size correlate inversely with risk, i.e. large and midsize cars have safer records than the average subcompact; but the correlation is not strong, much less strong than the correlation with measures of vehicle quality. For example, bottom-of-the-market subcompacts have much higher risk-to-driver than that of high-quality subcompacts. It remains unproven whether design features or subtle driver characteristics or behaviors are more important to risk. The importance of this inconclusive result for cars is that light cars are not necessarily less safe than heavy cars.

We have also shown that there are two groups of light trucks with unusually high risks: pickup trucks and conventional body-on-frame SUVs. These high fatality rates appear to be associated with their design:

(1) Body-on-frame (truck-based) SUVs and pickup trucks are the source of many excess deaths from rollovers and other one-vehicle crashes. Their high center of mass and narrow track width are largely responsible. New unibody SUVs have lower risks to their drivers, presumably because of their lower center of gravity and greatly reduced rollover risk.

(2) The high front ends (and probably the stiffness) of pickup trucks and truck-based SUVs cause many excess deaths in vehicles with which they collide, particularly when the truck strikes a car in the side (Joksch, 1998). This risk is spectacularly high for 3/4- and 1-ton

pickups. Unibody construction, now adopted in some new SUVs, greatly reduces that risk to drivers of other vehicles.

These associations of design with risk are convincing because in each case the physics relates to a specific structural attribute and a specific kind of observed crash. An attractive alternative to a truck-based SUV is the recently introduced unibody SUV. This design is relatively safe, and may prove much safer than typical body-on-frame SUVs. This is a preliminary result due to the small number of new vehicles of this type.

The dependence of the risk of traffic deaths on vehicle models is revealing, suggesting that the quality of cars may play a more important role in their risk than mass, and strongly confirming that the design of light trucks plays a major role in their high risk in fatal crashes. However, more research is needed to better quantify the relative importance of vehicle design and driver behavior in fatal crashes.

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